Evaluation of p-v-t properties data : the most probable values of compressibility factor of propane and propene

AUTHOR(S):

Date, Kaoru; Iwasaki, Hiroji

CITATION:

Date, Kaoru ...[et al]. Evaluation of p-v-t properties data : the most probable values of compressibility factor of propane and propene. The Review of Physical Chemistry of Japan 1974, 44(1): 1-10

ISSUE DATE:

1974-09-30

URL:

http://hdl.handle.net/2433/46993

THE REVIEW OF PHYSICAL CHEMISTRY OF JAPAN, VOL. 44, NO. 1, 1974

EVALUATION OF *P-V-T* PROPERTIES DATA

The Most Probable Values of Compressibility Factor of Propane and Propene

BY KAORU DATE AND HIROJI IWASAKI

The critical evaluation of the *P-V-T* data of propane and propene have been carried out based upon the experimental data available in literatures. All of the experimental measurements under high pressure were evaluated in view of their reliability and the data were correlated with temperature and pressure. The most probable values and the supplementary values of the compressibility factor of propane and propene are presented in the form of numerical tables covering the range of temperature from 248.15 to 548.15 K and that of pressure up to 300×10^5 Pa for propane, and from 248.15 to 498.15 K and up to 600×10^5 Pa for propene. The estimated uncertainty of the tabulated values is also presented in the tables.

Introduction

The evaluation of *P-V-T* properties of fluids at high pressure has been made as part of the program of "High Pressure Data Center of Japan" organized in the Society of Material Science, Japan, with the sponsorship of the Agency of Science and Technology. In the program, the work for the evaluation of *P-V-T* properties of gaseous methane, ethane and ethene had already been made and reported previously in this journal[1,2]. Next to them, this work for propane and propene has also been performed in a similar manner to the above cases. The following members of the Committee and researchers attended for the discussion on the present work:

J. Osugi and Y. Takezaki (Kyoto Univ.);
I. Tanishita (Nihon Univ.);
T. Makita and Y. Tanaka (Kobe Univ.);
K. Watanabe and A. Nagashima (Keio Univ.);
S. Takahashi (Tohoku Univ.),

to whom the authors wish to express sincere gratitude for their valuable suggestions and discussions.

(*Received May 24, 1974*)

1) J. Osugi, Y. Takezaki and T. Makita, *This Journal*, **41**, 60 (1971)
2) K. Date, K. Watanabe and M. Uematsu, *ibid.*, **43**, 92 (1973)

Survey and evaluation of *P-V-T* data

There exist eleven and seven measurements on the *P-V-T* relations of propane and propene, respectively, under high pressures. In Table 1, the authors, the temperature and pressure ranges, and reported numbers of isotherms are listed in the order of publishing year.

Table 1 Measurements of *P-V-T* properties of propane and propene under pressure

First author	Year	Temperature, ℃	Pressure, bar	No. of isotherms	Ref. No.
		Propane			
Sage	1934	21.1 to 104.4	1.7 to 206	6	3)
Beattie	1937	96.8 to 275	23 to 307	9	4)
Deschner	1940	30 to 366	1 to 141	12	5)
Lu.	1940	-30.5 to 20.5	5.1 to 61	6	6)
Reamer	1949	37.7 to 237.7	1 to 689	9	7)
Cherney	1949	50 to 125	10.8 to 49.7	3	8)
Stewart	1958	-196	1962 to 19620	1	9)
Dittmar	1962	0 to 140	9.8 to 1029	15	10)
Seeman	1963	5 to 26	4.6 to 8.9	Satd. liq. line	11)
Kahre	1964	-40 to 76.7	10.2 to 96.5	8	12)
Sliwinski	1969	10.5 to96.4	(No data)	Satd. vap. line	13)
		Propene			
Vaughan	1940	0 to 300	2.3 to 82.8	14	14)
Farrington	1949	4.4 to 237	1 to 689	12	15)
Marchman	1949	30 to 250	5.1 to 217	10	16)
Michels	1953	25 to 150	6.5 to 2869	7	17)
Stewart	1958	-196	1962 to 19612	1	9)
Dittmar	1962	0 to140	19.2 to 1028	15	10)
Robertson	1969	35 to 200	1000 to 10000	3	18)

The original papers were carefully read through and examined from the viewpoint of the reliability of the reported data, by the same operations as in the previous works[1,2]. The final evaluation was performed by the Committee members and several researchers in this field as described above.

As the results, the set of data for propene by Michels *et al.*[17] was considered to be the most reliable among them, and given the highest weight. The weight second to the above was given to two sets of data for propane by Reamer *et al.*[7] and Cherney *et al.*[8]. The weight third to the above was given to the sets of data for propane by Beattie *et al.*[4] and for propene by Marchman *et al.*[16]. The weight fourth

3) B. H. Sage, J. G. Schaafsma and W. N. Lacey, *Ind. Eng. Chem.*, **26**, 1218 (1934)
4) J. A. Beattie, W. C. Kay and J. Kaminsky, *J. Amer. Chem. Soc.*, **59**, 1589 (1937)
5) W. W. Deschner and G. G. Brown, *Ind. Eng. Chem.*, **32**, 836 (1940)
6) J. H. Burgoyne. *Proc. Roy. Soc.*, **A 176**, 280 (1940)
7) H. H. Reamer, B. H. Sage and W. N. Lacey, *ibid.*, **41**, 482 (1949)
8) B. J. Cherney, H. Marchman and R. York. Jr., *Ind. Eng. Chem.*, **41**, 2653 (1949)

The Review of Physical Chemistry of Japan Vol. 44 No. 1 (1974)

to the above was given to three sets of data for propane by Sage *et al.*[3], Deschner *et al.*[5] and Lu[6], and to the set of data for propene by Farrington *et al.*[15]. No weight was given to the remainders[9~14,16] in which some data were reported only in the extremely high pressure ranges, or the data along saturated vapor pressures, and the data with scarce numbers of significant figure of data compared with the others, or the like.

Methods and results of correlation

First, the *P-V-T* data in original papers expressed in various forms were reduced to the common expression Z with the SI units of pressure, volume and temperature:

compressibility factor, $Z=PV/RT$,

pressure, P, in 10^5 Pa (=1 bar=0.986923 atm),

specific volume, V, in cm^3/mol,

temperature, T, in K.

In these processes, the values of the atomic weights of carbon and hydrogen were adopted as C=12.011 ±0.001 and H=1.0080±0.0003 (recommended by IUPAC-1969). For the universal gas constant, R= 83.143±0.004 (cm^3-bar/K-mol), recommended by IUPAC-23rd Conference, was adopted. The maximum relative uncertainties of Z due to the uncertainties of atomic weights, which amount to 1.2×10^{-4} for propane and propene, are significantly lower than the experimental errors in the most precise measurement. Also, the relative uncertainty of Z due to the uncertainty of R amounts to 5.3×10^{-5}, which can be neglected even for the most precise measurement.

It is difficult to estimate the effect of the impurities on Z. However, all of the samples used were reported to be pure above 99.9% or above 99.7% at least, except in the case of 98.27% for propane by Deschner *et al.*[5], and these impurities were the hydrocarbons such as ethane and ethene having similar *P-V-T* properties to propane and propene. It is expected that the effect of impurities on Z is significantly little from these viewpoints. No correction was made in the above calculation of Z and the considerations on purity were taken into the evaluation together with other factors.

In the present correlations of the compressibility factor of propane and propene, the so-called grid-point method used in the early works[1,2] was employed predominantly. For the common and fixed grid-points of pressure and temperature, the following sets were employed:

temperature (°C): −25, 0, 25, 50,·····275 (interval of 25°C)

9) J. W. Stewart and R. I. La Rock, *J. Chem. Phys.*, **28**, 425 (1958)
10) P. Dittmar, F. Schulz and G. Strese, *Chemie-Ing.-Techn.*, **34**, 437 (1962)
11) F. W. Seeman and M. Urban, *Erdoel und Kohle-Erdgas-Petrochemie*, **16**, 117 (1963)
12) L. C. Kahre and R. J. Livingston, *Hydrocarbon Processing and Petroleum Refiner*, **43**, 119 (1964)
13) P. Sliwinski, *Z. Phys. Chem. (Frankfurt)*, **63**, 263 (1969)
14) W. E. Vaughan and N. R. Graves, *Ind. Eng. Chem.*, **32**, 1252 (1940)
15) P. S. Farrington and B. H. Sage, *ibid.*, **41**, 1734 (1949)
16) H. Marchman, H. W. Prengle, Jr. and R. L. Motard, *ibid.*, **41**, 2658 (1949)
17) A. Michels, T. Wassenarr, P. Louwerse, R. J. Lunbeck and G. J. Wolkers, *Physica*, **19**, 287 (1953)
18) S. L. Robertson and S. E. Babb, Jr., *J. Chem. Phys.*, **51**, 1357 (1969)

Table 2 Most probable values and supplementary values for the compressibility factor of propane

Pressure 10^5 Pa (=bar)	Temperature K (℃)												
	248.15 (-25)	273.15 (0)	298.15 (25)	323.15 (50)	348.15 (75)	373.15 (100)	398.15 (125)	423.15 (150)	448.15 (175)	473.15 (200)	498.15 (225)	523.15 (250)	548.15 (275)
1	0.97073 (0.00040)	0.97913 (0.00040)	0.98440 (0.00040)	0.98787 (0.00040)	0.99028 (0.00040)	0.99204 (0.00040)	0.99339 (0.00040)	0.99448 (0.00040)	0.99539 (0.00040)	0.99620 (0.00040)	0.99691 (0.00040)	0.99757 (0.00040)	0.99818 (0.00040)
5			0.9119*	0.9348 (0.0022)	0.9487 (0.0017)	0.9591 (0.0009)	0.9672 (0.0001)	0.9727 (0.0006)	0.9773 (0.0008)	0.9813 (0.0005)	0.9845 (0.0005)	0.9867*	0.9883*
10	0.03767*	0.03610*		0.8599 (0.0017)	0.8927 (0.0027)	0.9140 (0.0031)	0.9328 (0.0004)	0.9451 (0.0006)	0.9550 (0.0009)	0.9629 (0.0010)	0.9693 (0.0008)	0.9713*	0.9772*
20	0.07496*	0.07194*	0.07118*		0.7565 (0.0037)	0.8194 (0.0041)	0.8623 (0.0008)	0.8893 (0.0005)	0.9096 (0.0009)	0.9257 (0.0011)	0.9389 (0.0009)	0.9484*	0.9562*
30	0.1118*	0.1078*	0.1063*	0.1075 (0.0002)		0.7057 (0.0015)	0.7826 (0.0004)	0.8299 (0.0005)	0.8629 (0.0008)	0.8891 (0.0013)	0.9097 (0.0012)	0.9240*	0.9366*
40	0.1489*	0.1431*	0.1410*	0.1419 (0.0003)		0.5380 (0.0016)	0.6894 (0.0010)	0.7663 (0.0005)	0.8161 (0.0009)	0.8527 (0.0009)	0.8811 (0.0008)	0.9015 (0.0008)	0.9181*
50	0.1858*	0.1783*	0.1753*	0.1758 (0.0006)	0.1834 (0.0005)		0.5799 (0.0017)	0.6973 (0.0006)	0.7680 (0.0002)	0.8160 (0.0007)	0.8521 (0.0009)	0.8784 (0.0010)	0.9015 (0.0017)
60	0.2226*	0.2134*	0.2094*	0.2095 (0.0008)	0.2158 (0.0007)		0.4474 (0.0014)	0.6258 (0.0010)	0.7198 (0.0007)	0.7804 (0.0007)	0.8244 (0.0008)	0.8567 (0.0014)	0.8844 (0.0017)
70			0.2429*	0.2427 (0.0009)	0.2476 (0.0008)	0.2717 (0.0008)		0.5583 (0.0026)	0.6726 (0.0008)	0.7467 (0.0009)	0.7985 (0.0006)	0.8375 (0.0005)	0.8688 (0.0010)
80			0.2763*	0.2753 (0.0010)	0.2794 (0.0010)	0.2999 (0.0009)		0.5028 (0.0023)	0.6284 (0.0024)	0.7160 (0.0009)	0.7753 (0.0007)	0.8206 (0.0013)	0.8549 (0.0001)
90			0.3096*	0.3077 (0.0012)	0.3108 (0.0014)	0.3277 (0.0011)	0.3726 (0.0014)	0.4753 (0.0023)	0.5945 (0.0014)	0.6885 (0.0000)	0.7542 (0.0013)	0.8048 (0.0019)	0.8423 (0.0009)
100			0.3427*	0.3399 (0.0013)	0.3419 (0.0016)	0.3563 (0.0010)	0.3920 (0.0022)	0.4691 (0.0019)	0.5740 (0.0003)	0.6661 (0.0004)	0.7364 (0.0005)	0.7903 (0.0018)	0.8313 (0.0013)
110			0.3755*	0.3717 (0.0014)	0.3727 (0.0017)	0.3849 (0.0009)	0.4138 (0.0018)	0.4747 (0.0012)	0.5646 (0.0007)	0.6515 (0.0006)	0.7211 (0.0007)	0.7783 (0.0010)	0.8222 (0.0014)
120			0.4082*	0.4033 (0.0015)	0.4032 (0.0019)	0.4135 (0.0008)	0.4372 (0.0012)	0.4885 (0.0003)	0.5632 (0.0011)	0.6424 (0.0014)	0.7107 (0.0009)	0.7689 (0.0002)	0.8152 (0.0011)
130			0.4407*	0.4349 (0.0017)	0.4332 (0.0020)	0.4418 (0.0008)	0.4635 (0.0012)	0.5064 (0.0008)	0.5670 (0.0011)	0.6378 (0.0022)	0.7046 (0.0015)	0.7625 (0.0015)	0.8108 (0.0007)
140			0.4731*	0.4663 (0.0028)	0.4631 (0.0022)	0.4696 (0.0006)	0.4893 (0.0013)	0.5272 (0.0009)	0.5785 (0.0007)	0.6394 (0.0009)	0.7023 (0.0000)	0.7596*	0.8072*
150			0.5054*	0.4977 (0.0033)	0.4922 (0.0032)	0.4977 (0.0008)	0.5157 (0.0016)	0.5482 (0.0011)	0.5924 (0.0004)	0.6462 (0.0014)	0.7036 (0.0006)	0.7588*	0.8064*
160			0.5375*	0.5280 (0.0031)	0.5216 (0.0034)	0.5259 (0.0010)	0.5417 (0.0010)	0.5692 (0.0013)	0.6085 (0.0001)	0.6573 (0.0020)	0.7089 (0.0012)	0.7607*	0.8077*
170			0.5695*	0.5582 (0.0031)	0.5508 (0.0036)	0.5538 (0.0012)	0.5680 (0.0002)	0.5909 (0.0017)	0.6265 (0.0002)	0.6702 (0.0018)	0.7174 (0.0011)	0.7654*	0.8109*
180			0.6013*	0.5883 (0.0030)	0.5798 (0.0037)	0.5816 (0.0015)	0.5942 (0.0008)	0.6131 (0.0020)	0.6451 (0.0003)	0.6844 (0.0014)	0.7286 (0.0002)	0.7726*	0.8159*
190			0.6331*	0.6182 (0.0028)	0.6086 (0.0039)	0.6086 (0.0029)	0.6205 (0.0018)	0.6355 (0.0020)	0.6641 (0.0004)	0.6992 (0.0012)	0.7406 (0.0012)	0.7820*	0.8226*
200			0.6648*	0.6484 (0.0028)	0.6371 (0.0040)	0.6354 (0.0032)	0.6466 (0.0028)	0.6586 (0.0021)	0.6843 (0.0002)	0.7158 (0.0002)	0.7538 (0.0011)	0.7931*	0.8306*
250							0.7730 (0.0036)	0.7772*	0.7878 (0.0019)	0.8072 (0.0011)	0.8309 (0.0013)	0.8558*	0.8830*
300											0.9179 (0.0007)		0.9521*

: The most probable values

* : The supplementary values

( ) : Value of standard deviation

Table 3 Most probable values and supplemetary values for the compressibility factor of propene

Pressure 10^5 Pa (= bar)	Temperature K (℃)										
	248.15 (- 25)	273.15 (0)	298.15 (25)	323.15 (50)	348.15 (75)	373.15 (100)	398.15 (125)	423.15 (150)	448.15 (175)	473.15 (200)	498.15 (225)
1	0.97481 (0.00020)	0.98151 (0.00020)	0.98602 (0.00020)	0.98919 (0.00020)	0.99148 (0.00020)	0.99317 (0.00020)	0.99444 (0.00020)	0.99543 (0.00020)	0.99623 (0.00020)	0.99689 (0.00020)	0.99746 (0.00020)
5			0.9246 *	0.9450 *	0.9591 *	0.9640 *	0.9714 *	0.9767 *	0.9812 *	0.9847 *	0.9870 *
10			0.8354 (0.0006)	0.8792 (0.0006)	0.9073 (0.0010)	0.9274 (0.0003)	0.9418 (0.0003)	0.9530 (0.0004)	0.9618 (0.0008)	0.9692 (0.0005)	0.9740 (0.0006)
20				0.7154 *	0.7972 (0.0001)	0.8455 (0.0008)	0.8792 (0.0004)	0.9035 (0.0003)	0.9221 (0.0005)	0.9370 (0.0003)	0.9477 (0.0006)
30					0.6450 (0.0006)	0.7508 (0.0004)	0.8108 (0.0003)	0.8517 (0.0002)	0.8811 (0.0001)	0.9039 (0.0003)	0.9212 (0.0002)
40						0.6308 (0.0011)	0.7355 (0.0006)	0.7966 (0.0007)	0.8385 (0.0015)	0.8718 (0.0005)	0.8962 (0.0011)
50						0.4359 (0.0012)	0.6492 (0.0003)	0.7390 (0.0006)	0.7966 (0.0013)	0.8385 (0.0004)	0.8697 (0.0002)
60						0.2569 (0.0005)	0.5506 (0.0004)	0.6786 (0.0016)	0.7541 (0.0016)	0.8073 (0.0004)	0.8453 (0.0000)
70						0.2692 (0.0000)	0.4488 (0.0001)	0.6184 (0.0020)	0.7123 (0.0023)	0.7767 (0.0005)	0.8219 (0.0002)
80						0.2920 (0.0000)	0.3931 (0.0003)	0.5635 (0.0010)	0.6737 (0.0019)	0.7480 (0.0006)	0.7998 (0.0003)
90						0.3171 (0.0002)	0.3841 (0.0004)	0.5223 (0.0004)	0.6402 (0.0003)	0.7212 (0.0000)	0.7790 (0.0003)
100						0.3419 (0.0002)	0.3932 (0.0003)	0.4990 (0.0004)	0.6132 (0.0002)	0.6980 (0.0001)	0.7609 (0.0007)
110						0.3684 (0.0002)	0.4091 (0.0001)	0.4908 (0.0002)	0.5943 (0.0002)	0.6791 (0.0003)	0.7457 (0.0012)
120						0.3944 (0.0004)	0.4284 (0.0002)	0.4938 (0.0002)	0.5833 (0.0001)	0.6662 (0.0003)	0.7344 (0.0016)
130						0.4202 (0.0007)	0.4496 (0.0005)	0.5042 (0.0003)	0.5798 (0.0006)	0.6584 (0.0003)	0.7262 (0.0013)
140						0.4460 (0.0008)	0.4718 (0.0007)	0.5182 (0.0006)	0.5830 (0.0008)	0.6552 (0.0003)	0.7204 (0.0008)
150						0.4715 (0.0006)	0.4949 (0.0011)	0.5341 (0.0002)	0.5912 (0.0005)	0.6560 (0.0001)	0.7175 (0.0004)
160						0.4971 (0.0006)	0.5177 (0.0009)	0.5523 (0.0005)	0.6024 (0.0007)	0.6604 (0.0002)	0.7176 (0.0002)
170						0.5226 (0.0005)	0.5404 (0.0008)	0.5717 (0.0011)	0.6158 (0.0016)	0.6670 (0.0001)	0.7205 (0.0006)
180						0.5480 (0.0005)	0.5633 (0.0008)	0.5911 (0.0011)	0.6304 (0.0017)	0.6767 (0.0004)	0.7266 (0.0006)
190						0.5734 (0.0006)	0.5863 (0.0010)	0.6110 (0.0010)	0.6455 (0.0010)	0.6872 (0.0003)	0.7344 (0.0012)
200						0.5986 (0.0005)	0.6094 (0.0010)	0.6312 (0.0010)	0.6620 (0.0015)	0.7000 (0.0002)	0.7438 (0.0013)
250						0.7222 (0.0007)	0.7251 (0.0009)	0.7359 (0.0009)			
300						0.8429 (0.0007)	0.8382 (0.0008)	0.8412 (0.0004)			
350						0.9602 (0.0013)	0.9494 (0.0010)	0.9453 (0.0007)			
400						1.0756 (0.0017)	1.0588 (0.0014)	1.0479 (0.0014)			
450						1.1894 (0.0020)	1.1665 (0.0018)	1.1501 (0.0017)			
500						1.3015 (0.0022)	1.2727 (0.0022)	1.2505 (0.0021)			
600						1.5214 (0.0024)	1.4806 (0.0024)	1.4474 (0.0022)			

: The most probable values

* : The supplementary values

( ) : Value of standard deviation

pressure (bar): 1, 5, 10, 20, 30,·····200 (interval of 10 bar)
200, 250, 300, ·····500 (interval of 50 bar)
500, 600, 700,·····1000 (interval of 100 bar).

The values of Z at the above grid-points, Z_i, were obtained from the original data reported in respective works. When the data reported are not what were gained at one of the common grid-point specified, the interpolation procedures were carried out along an isotherm or an isobar on a digital computer using the least squares method. The precaution was paid for this procedure in order to retain the experimental accuracy for each original work. Then the mean value at each grid-point was calculated with the weights determined in the critical evaluation as described in the preceding section. The standard deviations σ were also calculated by the following expression:

$$\sigma=\sqrt{\frac{\Sigma[w_i(Z_i-\bar{Z})^2]}{(n-1)\Sigma w_i}}$$

where, w_i=the weight given,

Z_i=the compressibility factor in the original work,

$\bar{Z}$=the tabulated compressibility factor value.

n=the number of data sources.

The weighted mean compressibility factor values obtained for propane and propene are shown in the regions enclosed with dashed-lines in Tables 2 and 3, respectively, together with their standard deviations in brackets. Although every weighted mean value was determined independently of the adjacent values, the consistency among them was found to be satisfactory. Thus the committee recommended these weighted mean values as the most probables.

For propane and propene, the reliable values of Z at 1 bar cannot be obtained by extrapolating the experimental values of Z at high pressures to 1 bar. The authors collected the reliable data of the experimental second and third virial coefficients, B_T (in bar^{-1}) and C_T (in bar^{-2}) at low pressure for propane[4,5,7,19~28] and propene[15,17,28~32]. Then using the expression: $Z=1+B_TP+C_TP^2$, each value of Z at 1 bar and at each experimental temperature was calculated. Their equally weighted mean values at the grid-points on 1 bar were calculated applying the least square method to develop the compressibility factor into the power seires of temperature. In Tables 2 and 3, they are given as the recom-

19) J. D. Kemp and C. J. Egan, *J. Amer. Chem. Soc.*, **60**, 1528 (1938)
20) F. W. Jessen and J. H. Lightfood, *Ind. Eng. Chem.*, **30**, 312 (1938)
21) F. L. Casado, D. S. Massie and R. Whytlaw-Gray, *J. Chem. Soc.*, **1949**, 1746 (1949)
22) D. S. Massie and Whytlaw-Gray, *ibid.*, **1949**, 2874 (1949)
23) G. A. Bottomley, D. S. Massie and Whytlaw-Gray, *Proc. Roy. Soc.*, **A200**, 201 (1950)
24) C. B. Kretschner and R. Wiebe, *J. Amer. Chem. Soc.*, **73**, 3778 (1951)
25) P. P. Dawson, Jr. and J. J. McKetta, *Petroleum Refiner*, **39**, 151 (1960)
26) M. L. McGlasham and D. J. B. Potter, *Proc. Roy. Soc.*, **A267**, 478 (1962)
27) W. Kappalo, N. Lund and K. Schaeffer, *Z. Phys. Chem. (Frankfurt)*, **37**, 196 (1963)
28) J. A. Huff and T. M. Reed, *J. Chem. Eng. Data*, **8**, 306 (1963)
29) E. E. Roper, *J. Phys. Chem.*, **44**, 835 (1940)
30) H. W. Pfenning and J. J. McKetta, *Petroleum Refiner*, **36**, 309 (1957)
31) M. L. McGlasham and C. J. Wormald, *Trans. Faraday Soc.*, **60**, 646 (1964)
32) D. McA. Mason and B. E. Eakin, *J. Chem. Eng. Data*, **6**, 499 (1961)

mended values of Z at the normal pressure, together with the standard deviations.

Above 1 bar, there was only one source at each grid-point outside the dashed-lines in the tables, where the grid-point method could not be employed. The supplementary values of compressibility factor at these points were determined as follows.

For propane at -25 to 25°C and above 10 bar, and at 150°C and 250 bar, the interpolation procedures were carried out along the isobar at common-fixed pressure value over the temperature range to the points where the most probable Z values were already given. In the procedures, the sets of the original data at their experimental temperatures were fitted together to the cubic or quartic equations of temperature with the respective weights given in the Committee. And for propane at 250 and 275°C, up to 250 and 300 bar, the sets of the original data with their weights given were fitted to the polynomials of pressure, $Z=1+\sum_{n=1}^{n} a_n P^n$, along the respective isotherms. Similarly, for propene at respective temperatures, the interpolation procedures were carried out along the isotherms up to moderate pressures fitting the sets of the original data with the weights given to the same polynomials as above.

In all cases, the interpolated Z values were in excellent agreement with the most probable Z values and the deviations from the original data at the intended grid-points were less than the experimental errors reported by the original authors or evaluated by the Committee. Thus the interpolated values were recommended for the supplementary shown in the tables. Moreover, the supplementary Z values

Table 4 Uncertainty of tabulated Z values for propane

Pressure	Temperature K (℃)												
10^5 Pa (−bar)	248.15 (−25)	273.15 (0)	298.15 (25)	323.15 (50)	348.15 (75)	373.15 (100)	398.15 (125)	423.15 (150)	448.15 (175)	473.15 (200)	498.15 (225)	523.15 (250)	548.15 (275)
1	0.040%	0.040%	0.040%	0.040%	0.040%	0.040%	0.040%	0.040%	0.040%	0.040%	0.040%	0.040%	0.040%
5			0.35	0.25	0.20	0.15	0.10	0.10	0.10	0.10	0.10	0.15	0.20
10	0.75	0.75		0.25	0.30	0.35	0.10	0.10	0.10	0.10	0.10	0.15	0.20
20	0.75	0.75	0.75		0.50	0.50	0.10	0.10	0.10	0.15	0.15	0.15	0.20
30	0.75	0.75	0.75	0.45		0.30	0.10	0.10	0.10	0.15	0.15	0.15	0.20
40	0.50	0.50	0.50	0.40		0.30	0.15	0.10	0.10	0.15	0.15	0.15	0.20
50	0.45	0.45	0.45	0.35	0.35		0.30	0.10	0.10	0.15	0.15	0.15	0.20
60	0.45	0.45	0.45	0.40	0.35		0.30	0.20	0.15	0.15	0.15	0.20	0.20
70			0.70	0.40	0.35	0.35		0.50	0.20	0.15	0.15	0.20	0.15
80			0.70	0.40	0.40	0.35		0.50	0.40	0.15	0.15	0.20	0.15
90			0.70	0.40	0.50	0.35	0.40	0.50	0.25	0.10	0.20	0.25	0.15
100			0.70	0.40	0.50	0.30	0.60	0.45	0.15	0.10	0.15	0.25	0.20
110			0.70	0.40	0.50	0.25	0.45	0.25	0.15	0.10	0.15	0.15	0.20
120			0.70	0.40	0.50	0.20	0.30	0.20	0.20	0.25	0.15	0.15	0.20
130			0.80	0.40	0.50	0.20	0.30	0.30	0.20	0.35	0.25	0.20	0.15
140			0.80	0.65	0.50	0.20	0.30	0.20	0.15	0.20	0.15	0.20	0.20
150			0.80	0.70	0.65	0.20	0.30	0.20	0.10	0.25	0.15	0.20	0.20
160			0.80	0.65	0.65	0.20	0.20	0.25	0.10	0.30	0.20	0.20	0.20
170			0.80	0.60	0.65	0.25	0.20	0.30	0.10	0.30	0.20	0.20	0.20
180			0.75	0.55	0.65	0.25	0.20	0.35	0.10	0.25	0.15	0.20	0.20
190			0.75	0.50	0.65	0.50	0.30	0.35	0.10	0.20	0.20	0.20	0.20
200			0.70	0.45	0.65	0.50	0.45	0.35	0.10	0.20	0.20	0.20	0.20
250							0.50	0.40	0.25	0.20	0.20	0.20	0.20
300											0.10		0.20

Table 5 Uncertainty of tabulated Z-values for propene

Pressure	Temperature K (℃)										
10^5 Pa (−bar)	248.15 (-25)	273.15 (0)	298.15 (25)	323.15 (50)	348.15 (75)	373.15 (100)	398.15 (125)	423.15 (150)	448.15 (175)	473.15 (200)	498.15 (225)
1	0.020%	0.020%	0.020%	0.020%	0.020%	0.020%	0.020%	0.020%	0.020%	0.020%	0.20%
5			0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10
10			0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10
20				0.25	0.10	0.10	0.10	0.10	0.10	0.10	0.10
30					0.10	0.10	0.10	0.10	0.10	0.10	0.10
40						0.20	0.10	0.10	0.20	0.10	0.15
50						0.30	0.10	0.10	0.20	0.10	0.10
60						0.20	0.10	0.25	0.25	0.10	0.10
70						0.10	0.10	0.35	0.35	0.10	0.10
80						0.10	0.10	0.20	0.30	0.10	0.10
90						0.10	0.15	0.10	0.10	0.10	0.10
100						0.10	0.10	0.10	0.10	0.10	0.15
110						0.10	0.10	0.10	0.10	0.10	0.20
120						0.15	0.10	0.10	0.10	0.10	0.25
130						0.20	0.15	0.10	0.15	0.10	0.20
140						0.20	0.20	0.15	0.15	0.10	0.15
150						0.15	0.25	0.10	0.15	0.10	0.15
160						0.15	0.20	0.15	0.15	0.10	0.15
170						0.15	0.20	0.20	0.30	0.10	0.15
180						0.10	0.20	0.20	0.30	0.10	0.15
190						0.10	0.20	0.20	0.20	0.10	0.20
200						0.10	0.20	0.20	0.25	0.10	0.20
250						0.10	0.15	0.15			
300						0.10	0.15	0.10			
350						0.15	0.15	0.10			
400						0.20	0.15	0.15			
450						0.20	0.20	0.20			
500						0.20	0.20	0.20			
600						0.20	0.20	0.20			

at −25 and 0°C together with the original data at 10 bar, for propane, were fitted to cubic equations of pressure along the respective isotherms. Similar results as the above interpolations were obtained on the agreement of the values by the equations with the data used, and these calculated values at 10 bar were also tabulated for the supplementary.

The original data sources are few at most of the grid-points for propane and propene. Thus the standard deviations calculated have little significance in regard to the statistical meaning and they showed some unreasonable irregularities at some local grid-points practically. From these viewpoints, it is appropriate that the values determined as below are adopted for the uncertainty or the tolerance instead of the standard deviations. The standard deviations were plotted in graph against pressures on respective isotherms. The curves were drawn for respective sets of the standard deviations, with the

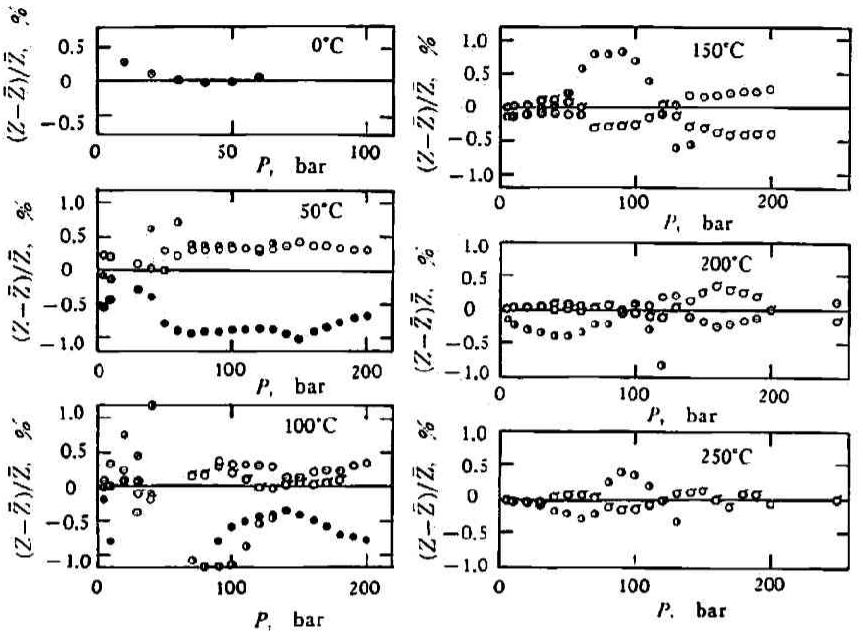

Fig. 1 Percentage departure diagrams for propane

● : 3), ○ : 4), ◗ : 5)
⊗ : 6), ⊙ : 7), ◔ : 8)

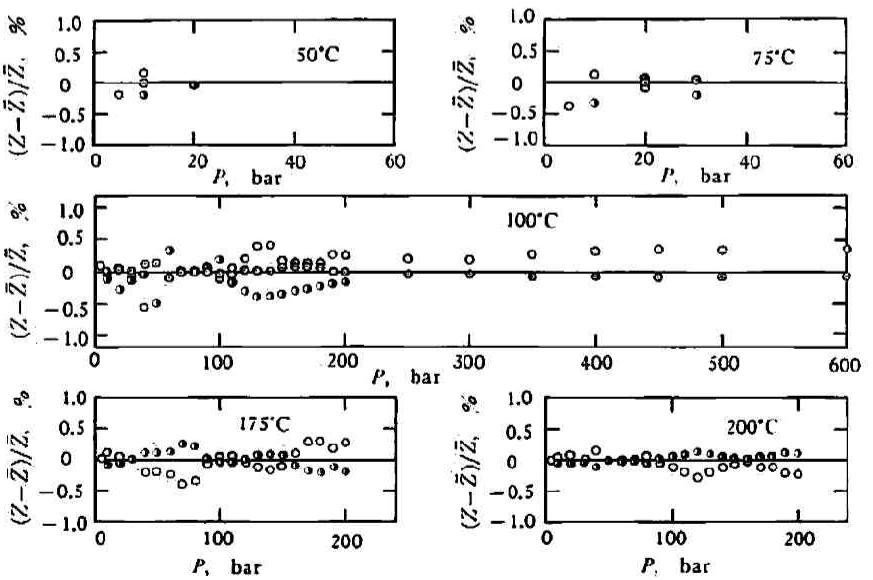

Fig. 2 Percentage departure diagrams for propene

○ : 15), ◗ : 16), ⊙ : 17)

precautions to keep in harmony with those of the adjacent isotherms and to exceed reasonably all of the points of the standard deviations. The values read from the curves were recommended as the uncertainties of the tabulated values of Z. They are shown in Tables 4 and 5, in the form of the percentage deviation calculated by the following definition:

$$\text{uncertainty}=\frac{100\times\hat{\delta}}{\bar{Z}},$$

where $\hat{\delta}$ is the absolute value of uncertainty of $\bar{Z}$ estimated as above and $\bar{Z}$ is the tabulated compressibility factor value.

The departures of the original data from the tabulated values were also calculated by:

$$\text{percentage departure}=\frac{100(Z-\bar{Z})}{\bar{Z}},$$

where Z is the compressibility factor interpolated from the original measurements and $\bar{Z}$ is the tabulated compressibility factor value. Some of them are given in Figs. 1 and 2.

The Chemical Research Institute
of Non-Aqueous Solutions,
Tohoku University
Sendai, Japan